A proximity focusing RICH detector for kaon physics at Jefferson lab hall A

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Abstract

Important information on the ΛN interaction can be obtained from High Resolution Hypenuclear Spectroscopy experiments with electromagnetic probes. A challenging experiment on electroproduction of hypernuclei is scheduled for 2003 in Hall A at Jefferson Lab. One of the challenges is the high performance particle identification system needed. The signal is expected to be rare compared to the very high pion and proton backgrounds due to the small electron and kaon detection angles. The "standard" Hall A PID apparatus (TOF and two aerogel threshold Cherenkov detectors) does not provide sufficient suppression of the background. Simulations and calculations have shown that a RICH detector would solve the problem. A proximity focusing fluorocarbon/CsI detector similar to the ALICE RICH detector has been designed, built, tested and commissioned. The results show that the detector performs as expected.
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1. Introduction

There is growing evidence that hyperons appear as the first of the strange hadrons in neutron star matter at around twice normal nuclear density and

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that the onset of the hyperon formation is controlled by the attractive hyperon-nucleon interaction, which can be extracted in practice only from hypernuclear data. Hypernuclei can be studied, for the first time with unprecedented energy resolution, in Hall A at Jefferson Lab, by means of electron scattering on nuclei with production of hypernuclei by replacing a nucleon with a lambda particle. The associated kaon is

detected in coincidence with the scattered electron. The hypernuclear spectroscopy experiment [1] that will run next year (2003), will look for small peaks in the (e,e′k) missing mass spectrum. The contamination of pions and kaons plays an important role. In fact electrons and kaons will be detected at a very forward angle (6°) so the pion and proton backgrounds are expected to be very high. The standard Hall A particle identification system (PID) is not sufficient [2]. In order to minimize the contamination an effective PID has been designed, built and tested. Two aerogel Cherenkov detectors with different indices of refraction will be used to reduce on-line the proton and pion contamination. A RICH detector, proximity focusing, with CsI photocathode and perfluorohexane as radiator, has been built to further improve the PID capabilities. The RICH features and performance will be illustrated in the following sections.

2. Detector description

The RICH detector is conceptually identical to one module of the ALICE HMPID [3], so we will only briefly summarize here the main characteristics of the detector. The RICH uses a proximity focusing geometry, a CsI gaseous photocathode, and liquid perfluorohexane radiator, 15 mm thick. The choice of the radiator is imposed by the momentum range (1–$3\,\text{GeV}/c$) of the particles to be identified. The Cherenkov photons, emitted along a conic surface, are refracted by the fluorocarbon-fused silica methane interfaces and strike a pad plane after traversing a proximity gap of 10 cm filled with methane. Fig. 1 shows the radiator and the photocathode. The 300 nm thick CsI photocathode is obtained by vacuum evaporation [4,5]. The QE has been measured on line during the evaporation process. The measurement results are compatible with the test beam results [5].

In order to tune the various elements of the RICH, the analytic estimate of the angle resolution of ALICE-HMPID has been revised and adapted and a new Monte Carlo program based on GEANT3 has been developed. Although Hall A RICH is exposed to a much lower particles per event than ALICE HMPID, the huge background of pions and protons and the high rejection ratio needed to unambiguously identify the hadrons makes the PID challenging. The simulation results are displayed in Fig. 2, showing the superior PID performances of the RICH. Fig. 2b shows the expected $^9\text{Be}(e,e'\text{K})^9\text{Li}_\Lambda$ excitation energy spectra obtained with the standard PID system and with the RICH.

2.1. The fluid systems

The gas system controls the flow, and measures its purity. The main purpose of this system is to avoid any contamination with oxygen or moisture that could eventually damage the CsI photocathode. Sensors detect Oxygen and moisture on

Fig. 1. The radiator: the quartz cylinder pattern reflects the necessity of withstanding higher pressure in part of detector due to the layout (1.c). (b) The photocathode (c) The RICH installed in the Hall A HRSH detector stack.
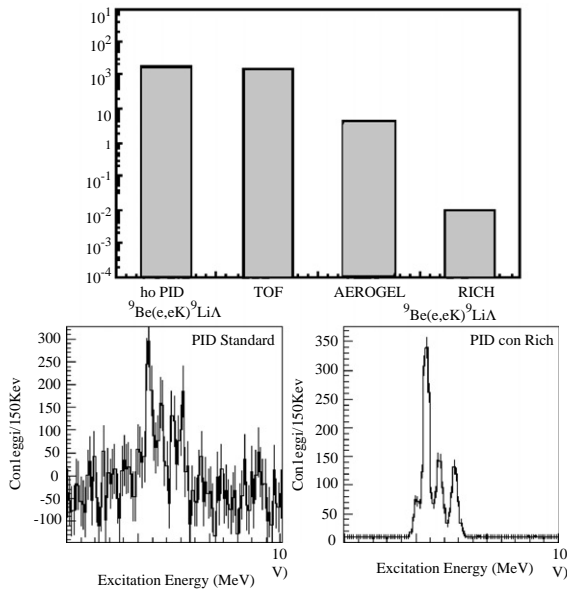
Fig. 2. (a) Contamination of pions and protons on the kaon signal with PID systems (TOF, TOF + aerogel, TOF + aerogel + RICH); (b) Spectrum obtained with and without RICH. (b) Spectrum obtained with and without RICH.

radiator. This maximizes filtering efficiency, minimizes the time required to purify the fluid, and minimizes turbulence inside the radiator. The fluid is degassed by bubbling high purity nitrogen through a bed of $2\,\mu m$ pore, sintered stainless steel cylinders and then through the liquid to scavenge air in solution in the fluid. The sintered stainless cylinders maximize the contact area between the nitrogen and the radiator liquid. This significantly speeds up the degassing of the radiator liquid. The nitrogen then passes through a cold condenser that removes the perfluorohexane from the air–nitrogen–perfluorohexane stream and returns the perfluorohexane to the tank. The fluid also passes over an alternating pair of molecular sieve filters before being pumped to the radiator. Several methods are used to verify the quality of the radiator fluid. The effluent from the degassing tank passes through an oxygen and moisture sensor. An on-line transmission monitor measures the transmission of the liquid in the return flow from the radiator. Periodically the return flow is temporally diverted through an optical sample cell (Fig. 3). The light from a Deuterium lamp, filtered to select the appropriate wavelength (184 nm) is passed through a beam splitter. Part of the light goes trough the sample cell before its intensity is measured by a photodiode, whereas the intensity of the other part of the light is measured with a second photodiode, which gives the reference. The ratio of those two signals is an approximate measure of the transmission of the

line. If a contamination above 10 ppm for the moisture and 100 ppm for the Oxygen is detected the flow of methane is shut off and a dry gas line is turned on.

The ultra-compact purification recirculates, purifies, and monitors the quality of the radiator fluid (perfluorohexane). The fluid is circulated with a hermetic magnetic drive pump. A fail-safe header tank isolates pump pressure from the quartz radiator and guarantees safe and consistent pressure in the radiator. A large overflow tube in the header tank limits the maximum pressure in the radiator. The pressure in the radiator is controlled by adjusting the position of the header tank relative to the fluid outlet at the top of the radiator. A tube connects the header tank to the inlet at the bottom of the radiator.

In order to get the minimum pressure that will allow circulation, the header tank is positioned less than a centimeter above the radiator outlet. The fluid is constantly recirculated through the header tank with a small fraction diverted through the
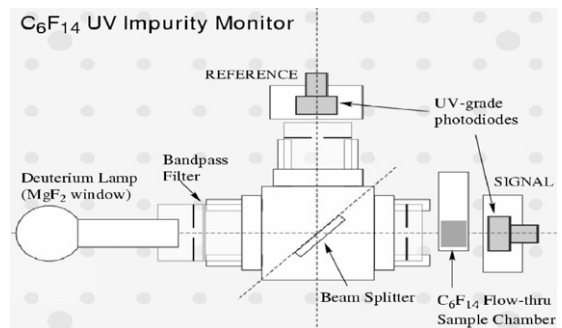

Fig. 3. Fluorocarbon purity monitoring system. The beam is passed through a beam splitter. Part of the light goes through the cell, the other to a REFERENCE diode.

liquid radiator in the selected wavelength range. This device can neither measure absolutely, nor does it measure the transmission spectrum. Therefore samples of the radiator liquid are taken regularly, and its transmission is measured off line by a vacuum spectrophotometer to calibrate the on line system.

2.2. Front end readout systems and DAQ limits

The RICH detector utilizes three photocathodes, each of them is divided into $48 \times 80 = 3840$ pads. In total 11520 detector channels have to be read out. The front end electronic (FEE) is arranged in 24 rows, each handling the signals of a group of 6 times $80 = 480$ pads. One row uses 30 GASSIPLEX [3] chips, to amplify, hold and multiplex the analogue signals. The charge content of these channels is digitized by a 10 bit FADC. The readout electronics therefore utilizes two types of CAEN VME modules: the V551 Sequencer and 12 V550 CRAMS two channel FADC. The sequencer provides the synchronization of the FEE with the corresponding FADC by generating the clock pulse for the FEE and the phase shifted convert signal for the FADC. One sequencer is used for all 24 groups/FADC channels. Forming the trigger and starting the read-out cycle, multiplexing and digitizing the signals and transferring the data from the CRAMS into the readout controller (ROC) takes 680 ms for a typical event (50 pads above pedestal), if the FADC is operated at 800 kHz, which is the maximum frequency in this setup using a linear clock. Using a more sophisticated clock the frequency has been increased to 2500 kHz leading to a processing time of 272 μs per event. The system will be further improved by grouping the pads into 48 instead of 24 rows with half the number of pads in each of them. The number of V550 CRAMS will be doubled, and the modules will be distributed over two crates, using two ROCs. Finally more sophisticated readout software with "block data transfer mode" and improved buffering will be used rates in excess of 1.5 kHz with reasonable dead times (less than 30%) will be reached with the RICH DAQ system.

3. Tests

3.1. Cern tests

The detector was tested at CERN (Fig. 4) in November 2000 in the T7 PS test beam experimental area. At that time the mechanics did not follow the specifications. In particular, the gap between the anode wire plane and the photocathode plane was smaller (1.6 mm) than designed gap (2.0 mm). In order to avoid HV trips in the chamber operated at nominal conditions, this required the use of an Ar/methane (76/24) gas mixture while the proportional chamber was operated at high voltage of 1500 V. In Fig. 4 summary of the results is shown. In the top-left panel the distribution of the number of "resolved clusters" within the fiducial zone, which is in effect the number of photoelectrons, is displayed. The average number of photoelectrons was 12.4 per ring, as shown in the figure. In the top-right panel the Cherenkov angle for $7 \text{ GeV}/c$ pions, as measured for each event averaging over all the clusters, is reported. An angular resolution of about 3.7 mr was observed in good agreement with the Monte Carlo predictions. The bottom panels show an example of two single event hit maps, weighted by the ADC values. The rings are clearly visible with a very low level of background. The detector performance was satisfactory; the
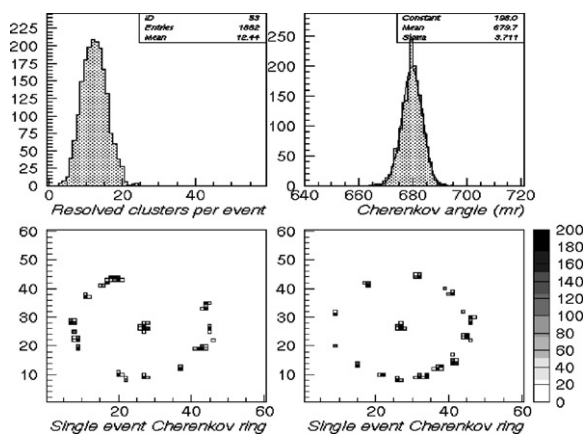

Fig. 4. CERN tests. Two typical events are shown. The number of resolved clusters is 12.5 (top left). The angle resolution is 3.7 mr (top right).

obtained results were even comparable to the expected performance for operating the RICH with methane at 2100 V.

3.2. Cosmic tests

The RICH detector has been tested with cosmic rays at JLab. The MWPC has been operated with pure methane and at a high voltage of 2100 V. A set of four scintillators served as trigger detectors mounted above and below the RICH detector. A coincidence between one upper and one lower scintillator started the readout. To achieve reasonable counting rates, rather large scintillators were chosen. The pair with the highest counting rate (0.05 Hz) covered an area of $15 \times 15\,cm^2$ and had an angular acceptance from $-11°$ to $4°$ with respect to the axis perpendicular to the radiator. These numbers have to be compared to the expected diameter of the rings (16 cm) and the angular acceptance of the RICH ($< 13°$) itself. So the scintillators did not provide sufficient tracking information to identify the point of intersection or the angle of the cosmic ray. To suppress particles with low energy, 55 cm of lead were placed between the upper and lower trigger scintillators. In Fig. 5 the results of one cosmic run are presented. Because no external tracking information was available, the data were analyzed in the following way: in the area of the detector covered

Fig. 5. Cosmic tests. Due to the lack of tracking information a wrong assignment of the MIP is possible. This leads to high background.

by the scintillators, the cluster with largest signal was identified as the Minimum Ionised Particle (MIP). All clusters within a circle of 40 cm diameter around this cluster were treated as clusters produced by Cherenkov light. Because of the asymmetric acceptance of the scintillators, the rings are in fact ellipses with the MIP in one focus. Due to the lack of tracking information, there is a probability of a wrong assignment of the MIP, which leads to a relatively high background compared to the CERN results. Along with the relatively large angles, this explains why the number of photoelectrons per ring is smaller than at CERN. Moreover, due to the higher atmospheric pressure at Jlab, achieving the same gain as at CERN requires operating the chamber at higher voltage.

3.3. In beam commissioning

During Jlab experiment E98-108 "Electroproduction of Kaons" the RICH detector was installed in the detector stack of the left HRS. Electron beams with energies of 3.4, 4.2 and 5.6 GeV were incident on 4 and 15 cm long liquid hydrogen targets. The standard HRS package was supplemented by two areogel detectors to improve the PID capabilities. The DAQ of the RICH could be operated either of two different configurations. In the so-called "stand-alone mode" it run independently of the HRS DAQ system. In this mode, no tracking information from the HRS detectors was available for the analysis of the RICH data. In the second configuration, the RICH DAQ was integrated into the HRS DAQ system. Raw data from all detector systems were written to the same data files. Therefore full tracking and PID information from the HRS and the RICH were combined. The data without tracking information are not useful to get the right Cherenkov angle. Unfortunately, it was possible to take only a small part of the data in the integrated mode. Fig. 6 shows the data obtained using the small sample of data with tracking information: the cluster distribution for a single event in the RICH and cumulated events showing the proton and the pion rings. Kaons lie in between. The number of kaons expected in the small statistical
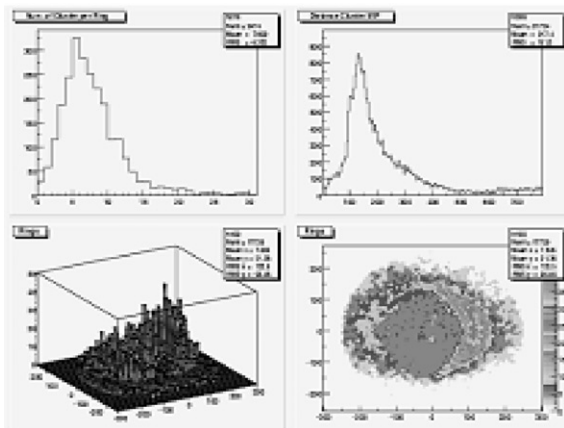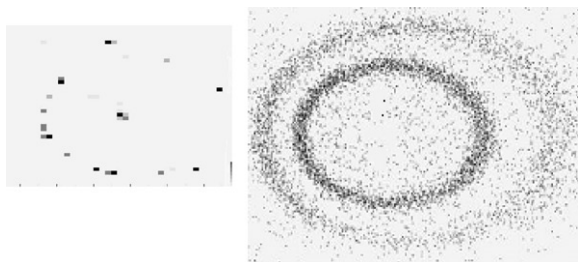
Fig. 6. On beam tests: (a) typical event, and (b) Overlapping of pions and protons rings. Kaons are in between.

sample is too small to allow the extraction of the "kaon signal."

4. Conclusions

Unambiguous kaon identification is needed for the hypernuclear spectroscopy experiment in Hall A of Jefferson Lab, Hall A. A proximity focusing fluorocarbon/CsI RICH detector has been built for this purpose. Test at CERN, with cosmics at Jlab, and first commissioning data with beam from Jlab show that the detector performs as expected.

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